Processing of SMD LEDs

Application note

Abstract

This application note provides a basic overview of the essential aspects and influencing factors regarding the processing of SMD LEDs.

Introduction

In general, LEDs do not essentially differ in terms of processing from other electronic SMD components.
Because of the optical properties, specific housing materials maybe somewhat more sensitive though, and LEDs can be rapidly impaired or may fail totally with regard to their electro-optical features if they are not correctly handled or assembled.
With progressive miniaturization and new housing concepts, requirements for LED processing are becoming more demanding, for example in respect to assembly or soldering processes.
With new Miniature High Power LEDs it is for example essential that the soldering process is designed and adapted so that defects (voids) in the solder joints are minimized. The lower the number of voids, especially at the thermal pad of the LED, the better the thermal connection to the PCB and thus the lower the thermal load. This in turn influences the performance and lifetime of the LED.
The possible extent of influence is diverse in such cases and is usually not determined by only a single processing step. Factors such as component finish, material and composition of the solder, design of the solder stencil, reflow solder profile or process atmosphere are interlinked and contribute to the solder result.

The professional processing of SMD LEDs from OSRAM Opto Semiconductors is outlined below. Essential aspects and important factors of influence within the manufacturing process are described.

Content

SMD LEDs

SMD LEDs are usually defined as devices with housings that can be soldered directly onto the surface of a printed circuit board via solder-capable contacts (Surface mounted device – SMD).
Plastic molding compounds, ceramic or epoxy substrates are used for the housing, cast with epoxy or silicone. According to the package type and variant, the contacts of traditional LED devices are usually formed as Gull-Wing or J-Leads.
With newer types of housing, especially for higher packing densities, the solder joints are small metal-coated connection surfaces on the backside of the housing (bottom only-terminated).
Fig. 1 shows a selection from the SMD LED portfolio of OSRAM Opto Semiconductors.

Fig. 1: Selection from the SMD LED product portfolio of OSRAM Opto Semiconductors

As with all products from OSRAM Opto Semiconductors, also its SMD LEDs fulfill the current RoHS guidelines (European Union & China), and therefore contains no lead or other defined hazardous substances.
Due to their geometric dimensions, beginning with a size of approx. 1 mm to 10 mm, SMD LEDs belong to the small constructions and are packaged in tapes of plastic because they are usually required in larger quantities.
The tapes with a width of 8 mm to 24 mm are coiled on a reel, whereby the reel size and the quantity on the roll are dependent upon the construction form.
The dimensions in accordance with IEC 60286-3, EIA 481-C of the LED-specific tape from OSRAM Opto Semiconductors can be found on the website in the Product Catalog section in chapter 6 "Tape & Reel" of the Short-Form Catalog, or else on the specific LED data sheet.

For storage and dispatch, the reels are packed in vacuum sealed dry bags (compliant to MIL-STD 81705C, type 1, class 1) together with desiccants and a moisture indicator card (Fig. 2).
The reels and dry bags are designated with a standard barcode product label (BPL). This label contains information about the manufacturer (OSRAM Opto Semiconductors), an indication of origin, product designation, batch number, date code, material number and quantity contained.

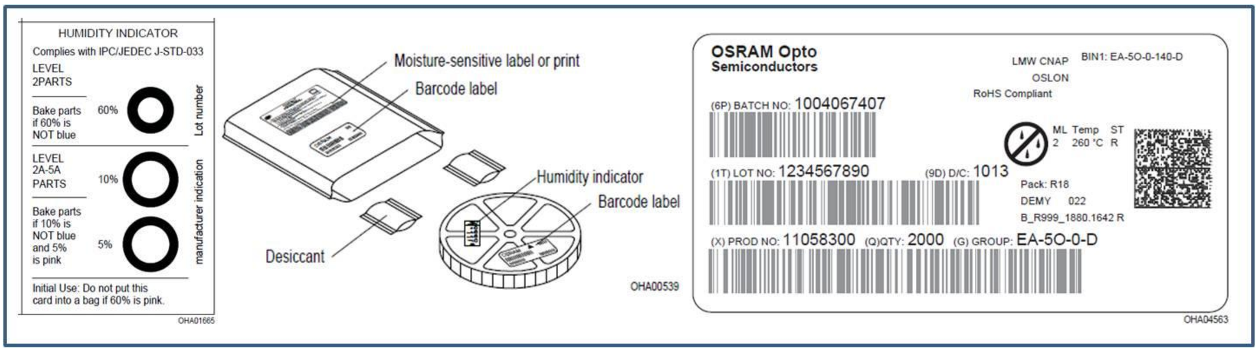


Fig. 2: Dry packing of SMD LEDs with Humidity Indicator (HIC) and Barcode Product Label (BPL)

The BPL also references the ESD-, and moisture sensitivity class, development designation, brightness class and grouping of the LEDs as supplementary information if required.
It is generally recommended to check the bag after receipt for damage and completeness.
No holes, dents or fissures of any type should exist that could impair the content.
For the storage of its SMD LEDs in unopened dry packaging, OSRAM Opto Semiconductors specifies a maximum storage time of 24 months (shelf life) with ambient conditions not exceeding 40 °C and a humidity content of max. 90 % RH (relative humidity). Further information can be found in the ZVEI guide for the long-term storage of components, assemblies and devices (“Leitfaden - Langzeitlagerfähigkeit von Bauelementen, Baugruppen und Geräten”).

It is necessary to check the moisture indicator card contained inside directly after opening and before processing of the components. The indicator changes color from blue to pink when the corresponding moisture grade is exceeded. If the color changes, the specified handling information (see HIC and moisture sensitive label – ML) must be observed and the components should be dry backed if necessary (also see JEDEC J-STD-033).
After opening the dry bag, LEDs have a specific floor life depending on their moisture level classification (according to JEDEC-STD-020D). The floor life specifies the time period after removal from a dry bag, dry storage or dry bake and before reflow soldering.

Moisture Sensitive Level	Floor Life
1	No limit
2	1 year
2a	4 weeks
3	168 hours
4	72 hours
5	48 hours
5a	24 hours
6	6 hours

Fig. 3: Moisture sensitive level vs. floor life

The information regarding the assigned moisture sensitive level (MSL) can be found in the corresponding data sheet of the LED or on the Barcode Product Label.

Note: The MSL makes no fundamental "statement" about the solder capability (solderability) of the components.

It is generally recommended to leave not required reels in their packaging, and to store components during processing in ambient conditions of ≤ 10% RH. Drying cabinets with dry nitrogen (N_2) or dry air are suitable for this type of storage.
With regard to dry packs, further information can be found on the Internet and in the Short Form Catalog in the “Tape and Reel” chapter, under the topic “Dry Pack”. Normative references such as JEDEC can also be found here.

Processing of SMD LEDs

Generally, SMD LEDs from OSRAM Opto semiconductors are compatible with existing industrial SMT processing methods, so that current populating techniques can be used for the mounting process.
Fig. 4 shows the process flow for processing SMD LEDs with the individual process steps.

For ideal mounting of the various SMD LED types to the circuit board, certain aspects should be taken into consideration.
For the manufacturing process the impact is diverse, and is usually not determined by only a single processing step.
Factors such as component finish, material and composition of the solder, design of the solder stencil, reflow solder profile or process atmosphere are interlinked and contribute to the solder result.
The influence of the PCB itself must also be considered as well as factors such as PCB material, solder pad design, surface quality and finish of the solder pad.
Information on the most important points is thus specified below.

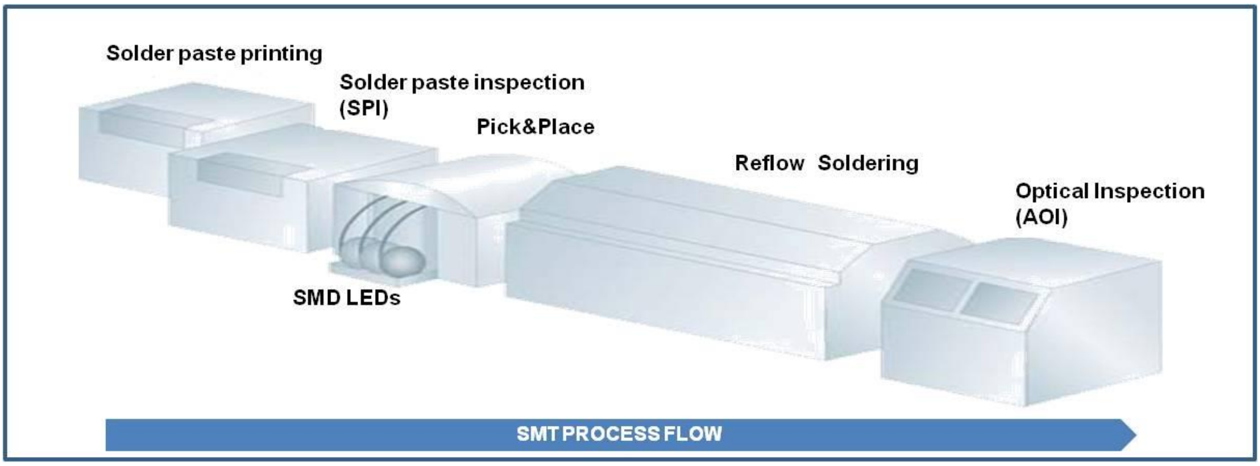


Fig. 4: Process flow for SMD LEDs

Solder pad design

Since the solder pad effectively creates the direct contact between the LED and the circuit board, the design of the solder pad decisively contributes to the performance of the solder connection.
The design has an influence on the solder joint reliability, the self-centering effect (self alignment) and heat dissipation, for example.
In most cases, it is therefore advantageous to use the recommended solder pad, since it is individually adapted to the properties and conditions of the LED. The corresponding solder pad can be found in the data sheet of each LED.

For the smallest possible positioning tolerance, the given designs show a compromise between the preferable non solder mask defined pads (NSMD) and the needs of good processing capability, a reliable solder connection and of course the requirements for good thermal management.
The copper area in the layout should be kept as large as possible, which dissipates and spreads the generated heat over the PCB and is typically covered with a layer of solder resist.
A typical compromise is a so-called half solder mask defined pad, as shown in Fig. 5.

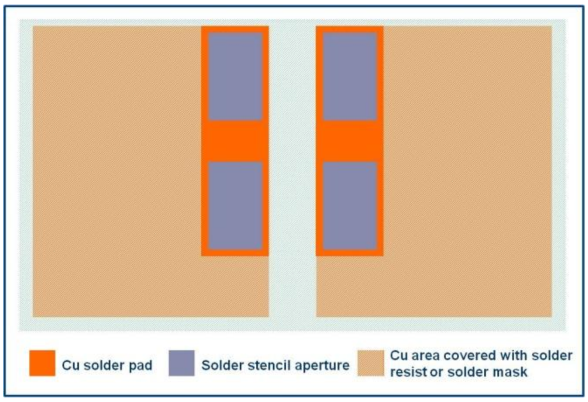


Fig. 5: Solder mask defined (SMD) / Half SMD pad design

However, it should be noted that the self-centering effect is limited in its extent. Slightly misaligned components (less than 0.150 mm) are automatically aligned during reflow due to the self-centering effect of the symmetrical pad design (Fig. 6).
If the placement position is offset more than 150 µm from the center, the components should not be reflowed, as electrical shorts resulting from solder bridges may occur.
Since the placement and rotational alignment of the component depends also on the process and equipment, optimization must take both factors into consideration.

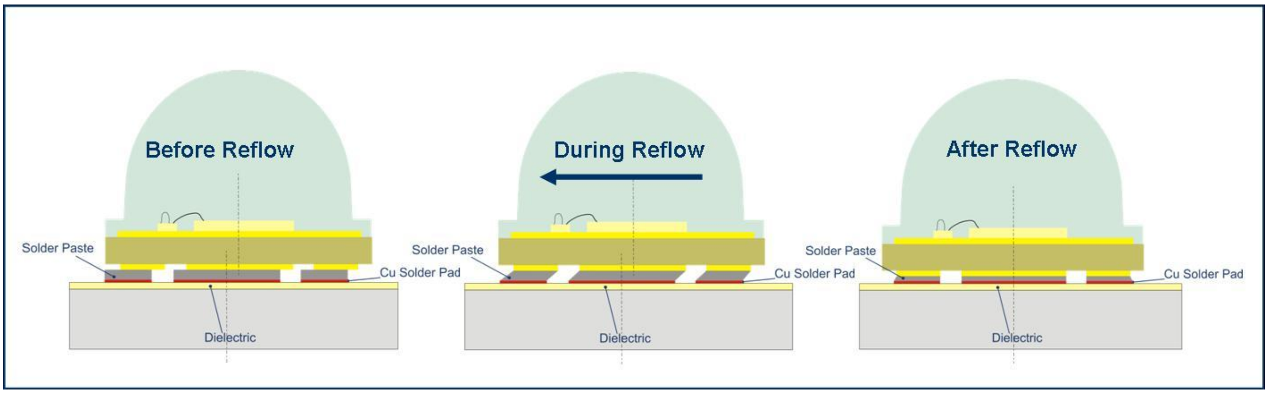


Fig. 6: Self alignment during reflow soldering (e.g. @ OSLON, OSRAM OSTAR SMT and OSRAM OSTAR Compact)

PCB pad finishes

In general, typical finishes (Fig. 7) are highly proven for SMT assembly, but with smaller solder pads the quality of the plating/finish is more important. Hot Air Solder Leveling (HAL/HASL) finishes are less preferred for assembly because of the uneven surface compared to completely "flat" platings such as Cu-OSP (OSP: Organic Solderability Preservative) or immersion Sn or NiAu (ENIG).

From a package point of view, it is difficult to recommend a certain PCB pad finish that will always meet all requirements. The choice of finish also depends strongly on board design, pad geometry, needs of other components on the board and process conditions, and must be specified according to the needs of the specific application.
Internal tests at OSRAM Opto Semiconductors have shown that Cu-OSP or NiAu offers suitable and reliable plating in most cases.

Finish / Solder Pad Plating	Typ. Layer Thickness [µm]	Advantages / Properties	Concerns
OSP (Organic Solderability Preservative)	0,3 – 0,5	lowest cost, fully planar surface, simple easy to operate process,	solderability degradation (storage conditions, multiple thermal cycles→N2 reflow) exposed copper
HAL / HASL (Hot Air Solder Leveling)	0,5 – 10	Low cost, widely usage, excellent wetting	Uneven surface, formation of humps, flatness of single pads, during process high thermal stress on PCB, residues (flux)
Immersion Sn (electroless)	0,3 – 1,3	Simple process, planar surface, only copper and solder in solder joint	Limited shelf life and storage, copper diffusion into Sn, baking or 2x reflow of PCB may be critical
Immersion Ag (electroless)	0,3 – 0,5	planar surface, wire bondable	Limited shelf life and storage, concerns of tarnishing / corrosion, baking or 2x reflow of PCB may be critical
Electroless Ni / Immersion Au (ENIG)	3 – 7 0,06 – 0,1	fully planar surface, very good shelf life	High cost, process control, compatible to solder mask, concerns of Ni corrosion (Black pad)
Electroless Ni / Electroless Pd / Immersion Au (ENEPIG)	3 – 7 0,05 – 0,15 0,01 – 0,1	fully planar surface, "universal Finish" solderable and wire bondable, reduce Au thickness, Pd reduces	High cost, process control, compatible to solder mask,

Fig. 7: Comparison of PCB finishes

Solder paste printing / solder stencil

As recommended by OSRAM Opto Semiconductor, the solder paste is normally applied via stencil printing. An appropriate solder stencil design is specified in the data sheet of the LED (Fig. 8). The amount to be applied as well as the quality of the paste deposits and the entire printing are primarily determined by the design of the printing stencil aperture and thickness, and are also influenced by the respective process.

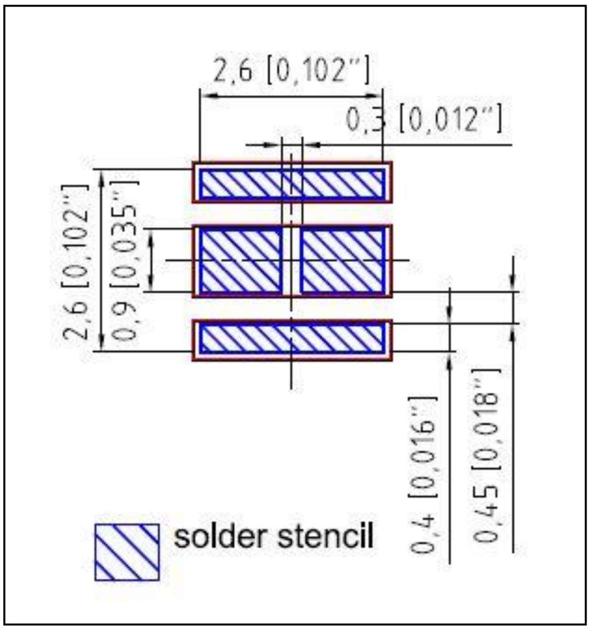


Fig. 8: Example of a stencil aperture for LEDs of the OSLON product family

The stencil apertures are typically smaller than the recommended solder pad. Stencil thickness used in the SMT industry varies from 100 µm to 150 µm (0.004 in to 0.006 in). OSRAM Opto Semiconductors typically recommends **120 µm** for SMD LEDs, resulting in a solder-joint thickness (standoff height) which is typically between 40 µm to 75 µm.

However, the stencil thickness used may also depend on other SMD components on the PCB.

For an ultra-compact high power SMD LED package such as OSLON Compact, OSRAM Opto Semiconductors has found in internal tests that an optimized stencil aperture and thickness may minimize tilting and result in very good self-alignment.
The two stencil aperture designs are shown in Fig. 9. In addition to the design itself, the thickness of the solder paste was adapted from 120 µm to 100 µm.

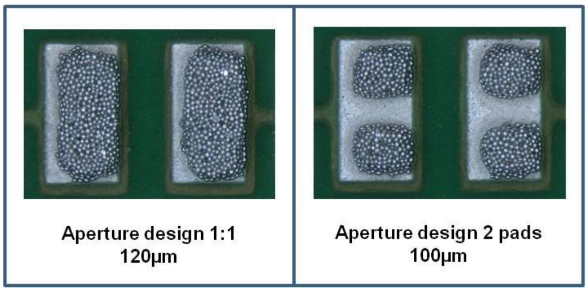


Fig. 9: Stencil aperture and proper solder paste print for OSLON Compact CM

The adapted design and thickness of the solder stencil result in significant improvements of the alignment and minimized tilting after reflow soldering (Fig. 10).

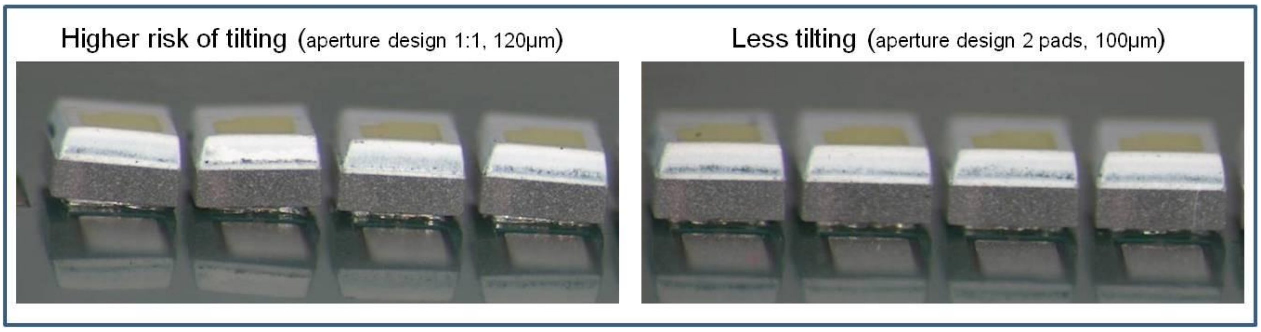


Fig. 10: Comparison of solder result for the different stencil designs and thicknesses (e.g. OSLON Compact CM)

3D SPI (Solder Paste Inspection)

The solder paste print process is potentially very unstable in the SMT industry, so that solder paste inspection (SPI) becomes necessary as a process evaluation and process control tool, especially with small component landing pads. Also for failure prevention it is recommended to check the solder paste volume regularly via solder paste inspection.

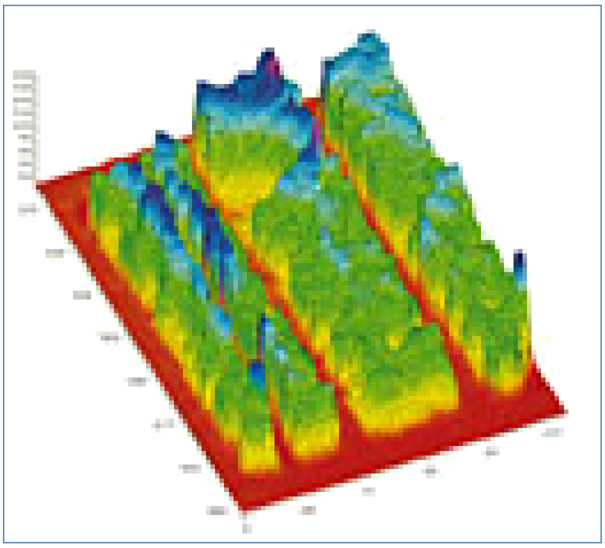


Fig. 11: Example of a solder paste thickness profile via 3D SPI

Pick & Place

Generally, SMD LEDs from OSRAM Opto Semiconductors are compatible with existing industrial SMT processing methods, where automated pick & place equipment provides the best handling and placement accuracy. In the Application Note “Recommended Pick & Place Tools (Nozzles) for LEDs of OSRAM Opto Semiconductors” a catalog with a linkage of the tools successfully tested is shown for the SMD LED product families.

When processing by means of automated placement equipment and based on in-house pick and place experiments, OSRAM Opto Semiconductors advises customers to take the following general pick and place guidelines into account:

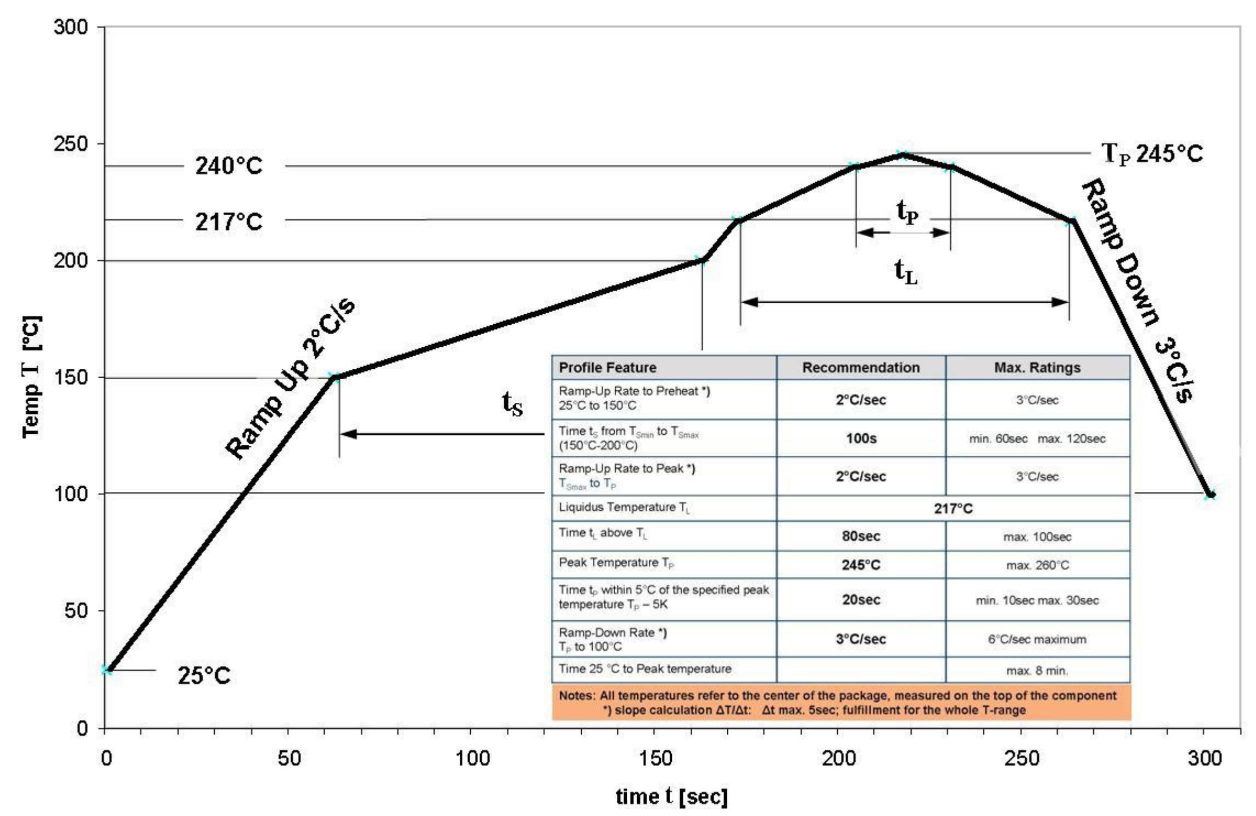
1. Care should generally be taken that an appropriate pick and place tool is used and that process parameters conform to package characteristics. As a starting point, a placement force of 2.0 N is recommended and should be minimized where possible.
2. The nozzle tip should be clean and free of any particles since this may interact in particular with the critical and optical relevant area (area over die/s and wire bond/s) of the LED package during pick & place.
3. To ensure zero defect, and in particular with LEDs, damage-free processing by the pick & place nozzle, it is a good practice to inspect the top surface of the LED under a microscope during setup and initial production runs.

Reflow soldering

The individual soldering conditions for each LED type according to JEDEC J-STD 020D can be found in the respective data sheets.
In this regard it must also be stated that JEDEC J-STD 020 D.1 does not represent production profiles for the user but for the component manufacturer for qualification and classification of its moisture-sensitive semiconductor components.

A standard reflow soldering process with forced convection under standard N_2 atmosphere is recommended for mounting the component, in which a typical lead-free SnAgCu metal alloy is used as solder. Fig. 12 shows the temperature profile for lead-free soldering with the recommended peak temperature of 245 °C.

In this context, it is recommended to check the profile on all new PCB materials and designs. As a good starting point, the recommended temperature profile provided by the solder paste manufacturer can be used. The maximum temperature for the profile as specified in the data sheet should not be exceeded though.



Profile Feature	Recommendation	Max. Ratings
Ramp-Up Rate to Preheat *) 25°C to 150°C	**2°C/sec**	3°C/sec
Time t_S from T_{Smin} to T_{Smax} (150°C-200°C)	**100s**	min. 60sec max. 120sec
Ramp-Up Rate to Peak *) T_{Smax} to T_P	**2°C/sec**	3°C/sec
Liquidus Temperature T_L	**217°C**	
Time t_L above T_L	**80sec**	max. 100sec
Peak Temperature T_P	**245°C**	max. 260°C
Time t_P within 5°C of the specified peak temperature T_P – 5K	**20sec**	min. 10sec max. 30sec
Ramp-Down Rate *) T_P to 100°C	**3°C/sec**	6°C/sec maximum
Time 25 °C to Peak temperature		max. 8 min.

Notes: All temperatures refer to the center of the package, measured on the top of the component
***) slope calculation ΔT/Δt: Δt max. 5sec; fulfillment for the whole T-range**

Fig. 12: Temperature profile for lead-free reflow soldering according to JEDEC JSTD-020

For lead-free reflow soldering it is strongly recommended to solder in a **nitrogen atmosphere**. The accelerated oxide growth occurring due to the increase in temperature during lead-free soldering is reduced significantly in the nitrogen atmosphere. This expands significant the process window again.
In particular, with the increasing use of new, lead-free component finishes such as Ag, NiPd, NiAu, NiPdAu or NiPdAu-Ag, with a nitrogen atmosphere and a residual oxygen content of < 500 ppm a significant improvement in wettability on the PCB surface and component metalization is achieved. Connected to this is also a distinct reduction of voids in the solder joint.
(see also the application notes “Further Details on lead free reflow soldering of LEDs” and “Measuring of the Temperature Profile during the Reflow Solder Process”)

After soldering it is generally recommended that all twisting, warping, bending and other forms of stress to the circuit board, especially with ceramic SMD LEDs, should be avoided in order to prevent breakage of the LED housing or solder joints.
Therefore, separation of the circuit boards should not be carried out manually, but should be carried out only with a specially designed tool.

Voids

For a good thermal connection and a high board level reliability it is recommended that voids and bubbles should be eliminated in all solder joints. A total elimination of voids, particularly for larger thermal pads (such as the OSLON family or OSRAM OSTAR Compact or SMT) is difficult however.
In industry standards such as IPC-A-610 D or J-STD-001D (which refer only to surface mount area array components such as BGA, CSP, etc.) the amount of voids (verified by the x-ray pattern) should be less than 25 %.

Internal studies and simulations at OSRAM Opto Semiconductors have determined however that for areas of up to 50 % of the

thermal pad area the voids only have a minor effect on the thermal resistance.
The limit of acceptable voiding can vary for each application and depends on the power dissipation and the total thermal performance of the system, affected by the PCB materials used.

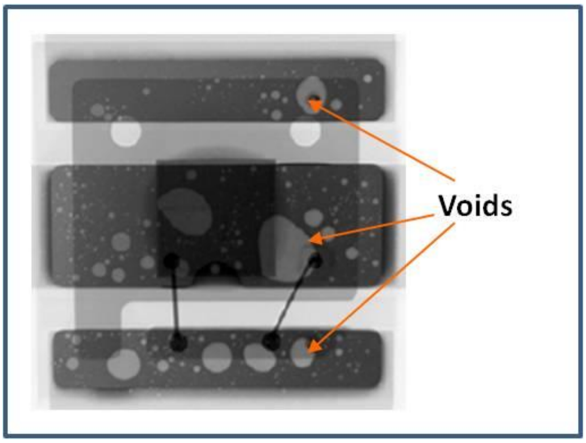


Fig. 13: X-ray image of a solder joint (e.g. OSLON)

The comprehension of the mechanisms for the creation of voids during reflow soldering and the complex issues existing with factors of influence and their interactions are being analyzed in the industry as part of projects such as "AK Poren (Void)".
These show that the individual factors mutually influence each other partly through contrary interactions. Thus for specific solder processes a complete approach must be utilized (Fig. 14).

Based on internal analyses by OSRAM Opto Semiconductors, the following general information for the minimization of voids can be deduced:

- The paste type (flux) has a major influence on wetting and porosity → Use of good wetting pastes, "low voiding pastes"
- Surface metallization of PCB: different PCB finish in combination with different solder paste may improve wetting
- Reflow profile; Parameters → Time above liquidus (TAL) > 80 s
- Solder atmosphere has significant influence, N_2 distinctly improves wetting dynamics → O_2 < 500 ppm

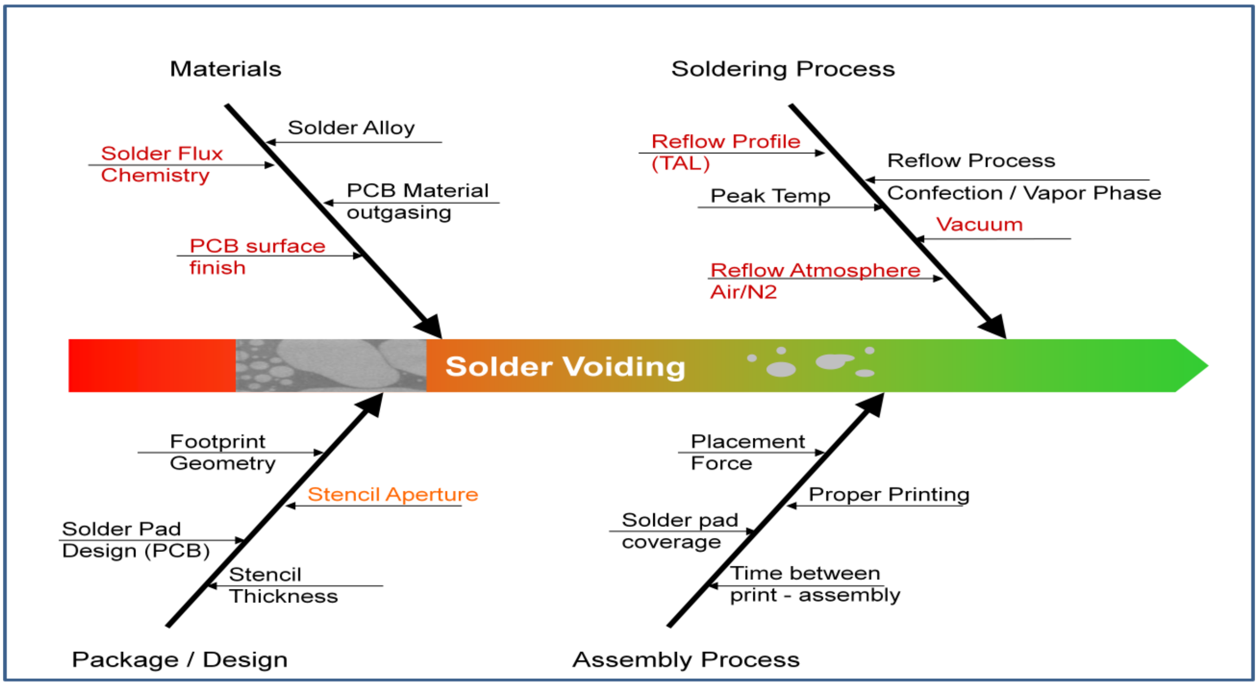


Fig. 14: Typical factors for affecting solder voiding (relevant factors in red)

- Design of the stencil aperture. The recommended design with smaller multiple openings in the stencil enables an out-gassing of the solder paste during the reflow soldering process and also serves to regulate the final solder thickness. →, Typical solder paste coverage of 50 %–70 % is recommended.

Solder Joint/post reflow inspection

After the reflow process, an automated optical inspection (AOI) is the state-of-the-art to check for final product quality.
For the most common SMD LEDs this is the simple and cost-efficient way to detect potential defects such as

- Displacement
- Tombstone
- Solder joint defects
- Defective dry joints & bridges
- Bent and lifted leads

SMD LEDs within the category of "bottom-only terminated" SMD components in IPC-A-610-D solder joint inspections are typically accomplished with transmission type x-ray equipment (similar to QFN packages).

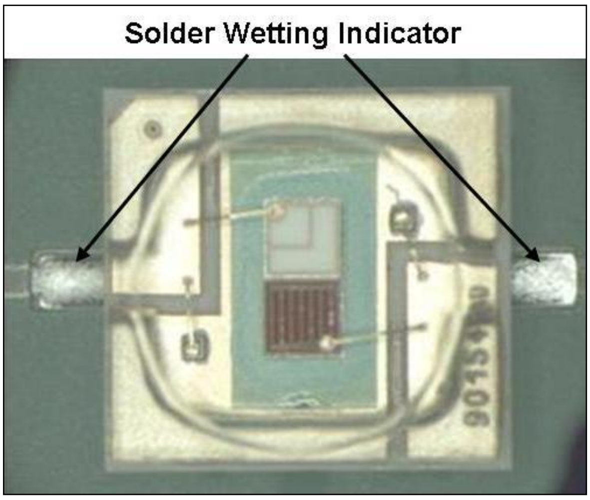


Fig. 15: Solder pad with solder wetting indicator (e.g. OSRAM OSTAR Compact)

X-ray inspection system (AXI) can detect bridges, shorts, opens, and solder voids.

In industry, x-ray inspection is typically used to define process settings and parameters and is then used to monitor the production process and equipment for process control, but is not performed as a 100-percent inspection.
To support the visual inspection of the solder wetting after reflow soldering, a so called "solder wetting indicator" can be additionally designed into the solder pad.

Storage

PCBs or assemblies containing LEDs should not be stacked so that force is applied to the LEDs, or should not be handled directly at the LED.

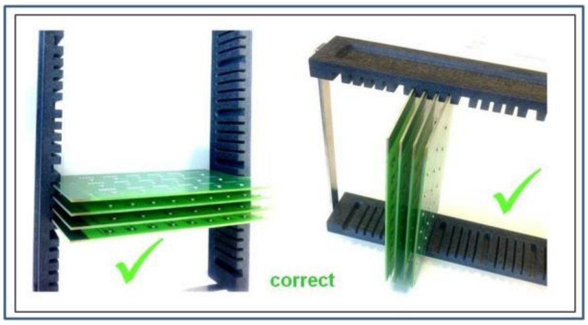


Fig. 16: Correct storage of LED assemblies

Generally, all LED assemblies should be allowed to return to room temperature after soldering, before subsequent handling, or the next process step.

Cleaning

Generally, isopropyl alcohol can be used for cleaning since this has been approved by OSRAM Opto Semiconductors as suitable for all types of SMD LEDs.

If other cleaning materials are used, their suitability must be tested beforehand, particularly as to whether or not damage is

associated with the LED and in respect to long term reliability.
Ultrasonic cleaning of LEDs is not recommended.
For dry cleaning, in addition to purified compressed air (e.g. a central supply or spray can), a clean, soft, lint-free cloth can be used, especially for LEDs with an epoxy encapsulant.
Dry cleaning of LED devices encapsulated with silicone is not recommended.
A combination of dry and wet cleaning may be required, depending on the type and extent of the contamination.
Special LED type-specific notes for cleaning can be found in the corresponding data sheets and in the application note "Cleaning of LEDs".

Summary

Generally, all SMD LEDs from OSRAM Opto semiconductors are compatible with existing industrial SMT processing methods, so that current populating techniques can be used for the mounting process.
Basic recommendations regarding solder pad/stencil design and reflow solder profile can be found in the corresponding data sheet of the LEDs.
On the website of OSRAM Opto Semiconductor in the Application section, additional notes are published regarding processing, specific LED-types, thermal management etc.

When developing circuitry, special attention should be given to the position and orientation of the LED on the circuit board.
Depending on the position and orientation of the LED, the mechanical stress on the LED may vary.

OSRAM Opto Semiconductors supports its customers during their development and design processes in order to help them to find the best possible solution for a specific application.

Appendix

Don't forget: ledlightforyou.com is the place to go whenever you need information and a list of worldwide partners for your LED lighting projects:

www.ledlightforyou.com

Authors: Kurt-Jürgen Lang, Andreas Stich

ABOUT OSRAM OPTO SEMICONDUCTORS

OSRAM, Munich, Germany is one of the two leading light manufacturers in the world. Its subsidiary, OSRAM Opto Semiconductors GmbH in Regensburg (Germany), offers its customers solutions based on semiconductor technology for lighting, sensor and visualization applications. Osram Opto Semiconductors has production sites in Regensburg (Germany), Penang (Malaysia) and Wuxi (China). Its headquarters for North America is in Sunnyvale (USA), and for Asia in Hong Kong. Osram Opto Semiconductors also has sales offices throughout the world.
For more information go to www.osram-os.com.